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Precision Agriculture Adoption Continues to Grow

Rapid technological change has been a prominent feature of U.S. agriculture. Increased competitive pressures from international and domestic markets, yield potential, and environmental concerns motivate farmers to pursue and adopt innovations. A relatively new technology-based approach, precision agriculture (PA), appeared during the early 1990s.

Precision agriculture is generally described as the incorporation of modern information technologies into the management of agricultural inputs and production practices. The U.S. Congress defines it as "an integrated information and production-based farming system designed to increase long-term, site-specific, and whole farm production efficiencies, productivity, and profitability while minimizing unintended impacts on wildlife and the environment."

Most definitions of PA stress the management of variability (e.g., in soil quality, nutrient levels, and pest infestation), which is common within most fields, in order to enhance economic benefits, and to reduce risks to the environment from agricultural production. Precision agriculture uses information technologies to match agricultural inputs (e.g., seeds, fertilizer, pesticides, irrigation water) with crop needs or potential. Application of inputs is customized for different areas within the field, instead of treating a whole field as a single unit.

A site-specific approach allows producers to apply appropriate types and amounts of inputs, increase yields, reduce application costs, and maintain the quality of air, land, and water resources. PA technologies fall into two broad categories:

- **Spatial and/or temporal sensing technologies.** Yield monitors, yield maps, geo-referenced soil maps, and remotely sensed maps are used in detecting and recording variation in yields, soil attributes, or crop conditions within a farm field, including pest infestations and water or nutrient availability.

- **Application control technologies.** Also called variable-rate technologies (VRT), these use information from sensing technologies to spatially vary input application rates and timing for seed, fertilizer, and pesticides. Machine guidance technologies linked to the Global Positioning System (GPS) are also commercially available to enhance the efficiency of input applications and tillage operations.

The survey data presented in this article are from USDA's annual **Agricultural Resource Management Survey** (ARMS). This survey collects field-level production input and practice data and farm-level economic data. For further information: www.ers.usda.gov/briefing/ARMS/howarmsisconducted.htm

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Precision agriculture is a suite of technological tools that can be adopted individually or in combinations. Data on adoption of PA technologies tend to reflect this diversity.

Using the Technological Tools

Among producers of the four major field crops (corn, soybeans, wheat, and cotton), corn and soybean farmers have been the most rapid adopters of PA sensing technologies. In general, the share of corn and soybean planted acreage using yield monitors, or for which yield or geo-referenced soil maps were available, was more than twice that of wheat or cotton. USDA's annual Agricultural Resource Management Survey found that while use of yield monitors in wheat production has grown steadily since 1996—from 6 percent of acreage to about 10 percent in 2000—use in corn and soybean acreage grew even faster, reaching nearly 30 percent for corn and over 25 percent for soybeans. Yield monitor use grew to over 33 percent of all planted corn acreage in 2001.

Cotton yield monitors have only recently become commercially available. Some of the recent growth in yield-monitored acreage has likely been facilitated by availability of combines with factory-installed yield monitors—an alternative to the retrofitted combines in use in the early 1990s.

Somewhat surprisingly, only about a third of corn and soybean acres reporting use of yield monitors also report producing a yield map—indicating that most yield monitor data is not geo-referenced and therefore not available for spatially vary-

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From Data to Decisions

Information stage	Information technology
Soil and plant data collection	***Global Positioning System (GPS)*** ***Sensing technologies:*** *Soil sampling, crop scouting, remote sensing, and yield monitoring*
Data analysis	***Decision support systems:*** *Yield maps, Geographic Information Systems (GIS), crop growth models, and input amount, placement and timing recommendations*
Input application	***Global Positioning System (GPS)*** ***Variable rate applicators for:*** *Fertilizers, manure, micronutrients, lime, herbicides, insecticides, seeds, and irrigation water*

Use of Yield Monitors Is Associated with Farm Sales Class and with Level of Operator Education

Characteristic	Corn	Soybeans	All wheat	Cotton
	(Percent of planted acres in category)			
Farm sales class				
< $100,000	14	12	6.9	1
$100-$500,000	27	23.6	10.9	*
> $500,000	46.8	43.6	15.8	1.9
Years of operator experience				
< 10	35	28.4	11.8	1.8
11-25	27.1	24.4	12.9	1.7
> 25	29.9	25.5	8.6	*
Education of operator				
< High school	12.9	14.8	2.6	*
High school	26.4	21.7	10.7	*
> High school	34.5	31.2	10.9	1.8

2001 data.
*Less than 1 percent.
Source: Agricultural Resource Management Survey, USDA

Economic Research Service, USDA

VRT Is Used More Widely for Applying Fertilizer Than for Seed or Pesticides

	For application of:			For application of:		
	Fertilizer	Seed	Pesticides	Fertilizer	Seed	Pesticides
	Percent of planted acres					
Year						
	Corn			**Soybeans**		
1998	7.6	2	1.3	6.9	*	0.6
1999	10.5	2.8	1.2	7.1	1.5	1.5
2000	10.6	3.3	2.9	5.6	1.8	1.3
	All wheat			**Cotton**		
1998	1.8	1.1	1	2.6	1.4	1.6
1999	NA	NA	NA	1.9	2	2.5
2000	3	*	*	4.2	1.6	2.4

*Less than 1 percent. NA=Not available.
Source: Agricultural Resource Management Survey, USDA

ing input applications (at least not automatically).

Anecdotal information suggests that, even without geo-referencing, yield monitors can offer significant benefits. Besides helping manage field variability, yield monitors may help the operator:

- guide field improvements, such as drainage and leveling;
- monitor moisture levels during harvest to help reduce drying costs;
- conduct in-field agronomic experiments (e.g., yield trials on crop varieties).

Adoption of VRT for input application tends to be much less prevalent among the major field crops than adoption of sensing technologies. Although the share of acreage using VRT has increased marginally across all inputs and crops over time, the most widespread use has been for fertilizer use on corn and soybeans. Many early uses for PA focused on nitrogen and phosphate application to corn and soybeans.

The relatively low VRT adoption rates for other crops and inputs likely reflect the small amount of acreage for which geo-referenced yield data are available as well as the scarcity of site-specific agronomic recommendations available to producers in many states (e.g., from an Extension service or from input or technology dealers). However, by 2000 over 10 percent of all cotton and wheat acreage, 17 percent of all soybean acreage, and over 20 percent of corn acreage were reported to have geo-referenced soil maps—indicating that many fields have some soil information available that would be useful for making spatially variable input decisions. The geo-referenced soil mapping data were generated largely through use of GPS technology in conjunction with soil testing for such attributes as residual nutrient levels and pH.

Other survey data indicate that, on about 5-10 percent of corn and soybean planted acreage, yield and/or soil attributes are being geo-referenced while variable-rate application of fertilizer, pesticides, and/or seeds is also being performed. This is the acreage on which PA technologies are being fully utilized to manage inputs.

Who Adopts Precision Agriculture?

Farm-level studies of the economic benefits and costs of complete PA systems, or individual components, are limited. However, the adoption rates for yield monitors are an indirect indication that producers are deriving economic benefits from this particular technology. One of the most comprehensive reviews of studies of PA

Selected Precision Agriculture Technologies: Adoption Is Generally Increasing Over Time

Technology/year	Corn	Soybeans	All wheat	Cotton
		Percent of planted acres		
Yield monitor				
1996	15.6	12.6	6.1	NA
1997	17.3	12.2	7.3	NA
1998	18.5	18.6	7.9	*
1999	24.3	19.7	NA	2.2
2000	29.6	25.4	10.4	1.2
Yield map				
1996	NA	5.3	*	NA
1997	7.7	5.4	*	NA
1998	6.7	8.8	*	*
1999	11.6	8.5	NA	*
2000	10.7	8.2	1.7	*
Geo-referenced soil map[1]				
1998	13.1	12.1	5.9	2.8
1999	16.7	14.7	NA	10
2000	21.9	17.1	11.1	13.1
Remotely sensed map				
1999	6.7	5.3	NA	NA
2000	5.2	4.2	3.1	NA

*Less than 1 percent. NA=Not available.
1. Share of acres geo-referenced is a cumulative rather than annual estimate. Respondents were asked whether their field had ever been geo-referenced, not whether the geo-referencing was done in a specific year.
Source: Agricultural Resource Management Survey, USDA.

Economic Research Service, USDA

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Geo-referencing—the process of associating position information (location) with field data, such as yields, soil type, soil test results, and insect and weed infestation.

GPS (Global Positioning System)—a space-based navigation system. Positioning is achieved through the use of simultaneously received transmissions from four or more satellites above the horizon. A GPS receiver matches latitude, longitude, and altitude information with data obtained from a specific site on the field.

GIS (Geographic Information System)—the integration of hardware, software, data, organizations, and institutional relations to automate, manage, analyze, and display geo-referenced information.

Yield monitors—devices that estimate crop yield per area of a field by measuring the quantity of the crop and the area covered by the harvester.

Yield mapping—the process of collecting geo-referenced data on crop yield and crop characteristics, such as moisture content, while the crop is being harvested. A yield mapping system, typically using GIS, combines the output of a yield monitor with the position information provided by a GPS receiver.

Remote sensing—acquisition of information by a recording device not in physical contact with an object being studied. Devices such as cameras, radar, lasers, or radio receivers can collect information from remote locations such as airplanes or satellites.

Variable-rate technologies (VRT)—a system that varies the rate of agricultural inputs such as seed, fertilizer, and crop protection chemicals in response to varying conditions in specific areas of a field.

[Source: National Research Council]

profitability was conducted by Purdue University, which found that about 60 percent of the studies indicated positive returns for a given PA technology, about 10 percent indicated negative returns, and the remainder showed mixed results.

Farm size is perhaps the most striking attribute positively associated with PA adoption. Innovations with large fixed acquisition or information costs are typically less likely to be adopted by smaller farms since there are fewer acres over which to spread these costs. Estimates of capital costs for a complete yield monitoring information system for one combine (i.e., yield monitor, GPS receiver, memory card, computer, software, training, and installation) range from $10,000 to $15,000. Despite these costs, even among farms with less than $100,000 in annual sales, yield monitors are being used on a substantial share of planted corn and soybean acreage.

There is also regional variability in the adoption of PA. Concentration of yield monitor use in the Heartland and Northern Crescent regions may be attributed to the fact that yield monitors were first introduced for corn and soybean harvesters. These regions are major corn and soybean producers, and a sizeable PA service sector has become established there.

What About the Future?

Several factors may be impeding more rapid PA adoption:

- incompatible components (for example, between different PA technology providers),
- lack of well-established, site-specific agronomic relationships (e.g., soil attributes and yield) which often vary annually, depending on weather conditions, and across the field;
- extensive producer training requirements for implementation;
- commodity-specific nature of many technologies; and
- capital requirements.

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Uncertainties about the impact of adoption on yields and input use have also been cited as factors contributing to modest adoption rates for some PA technologies. Despite these constraints, analysis by USDA's Economic Research Service (ERS) suggests steady growth in the adoption of PA technology during the next few years.

The active network of public and private research and development organizations involved with PA will likely facilitate adoption by generating farm management decision systems that assist producers in extracting economic or environmental benefits from their extensive geo-referenced soil, plant, and yield data bases. Development of PA technologies for specialty crop and livestock production is underway, as is commercialization of on-the-go or real-time sensing and input application instruments—allowing, for example, sensing and application to be accomplished in one trip over a field.

The predictable decline in information technology costs, development of more user-friendly technology, and growing computer capacity will all promote adoption. Government use of geographic information systems (GIS) for extension and technical assistance will expose producers to geo-spatial technologies. In addition, technology is being developed for commodity trait monitoring (e.g., oil and protein content), identity preservation, and traceability that may allow producers to use PA to take advantage of premiums offered in specialty markets. AO

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Read more…

Cooperative State Research, Education, and Extension Service (CSREES), USDA www.reeusda.gov/1700/programs/IFAFS/IFAFS.htm

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The U.S. Congress defined precision agriculture in Public Law 105-185: Agricultural Research, Extension, and Education Reform Act of 1998 [Title IV--Section 403].

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